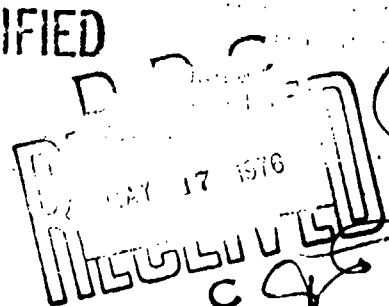


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A MORE RATIONAL APPROACH FOR ANALYZING AND DESIGNING  
THE STEEL CARTRIDGE AND CHAMBER INTERFACE

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With the use of Prandtl's constitutive equations of plasticity, a more rational nonlinear elastoplastic method has been developed for analyzing and designing the steel-cased cartridge and the chamber under actual firing conditions (while the cartridge case is loaded near the maximum material-carrying capacity) to remedy the sticking problem. In contrast to the usual assumption that the chamber is rigid, the chamber is considered to be deformable in this investigation. Both nonlinear material response and geometric nonlinearity have been taken into consideration. Nonlinearity of material properties has been taken into account by use of theories of plasticity. An incremental loading procedure has been used to consider large deformation of a cartridge case. The interaction of a steel-cased cartridge and the chamber of a gun has been studied parametrically. To achieve a uniform and improved performance of a steel-cased cartridge, guidance for the selection of design variables such as cartridge and chamber material properties, chamber pressure, cartridge configuration, the initial clearance between a case and a chamber, and the configuration of the chamber of a gun, have been graphically presented in this paper. Thus, information can be readily applied to the actual steel cartridge case and the chamber design.

INTRODUCTION

Cartridge cases for small-arms ammunition have been traditionally designed and made of brass[1]. However, because of the limited natural supply of brass and its predominant use in small arms ammunition, a strategic significance has been attached to it. With the increased emphasis on firepower and the inadequate domestic supply of

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brass, the use of this material during a major war could become critical. Hence, identification of alternative materials for small-arms ammunition cartridge cases is very important. Aluminum and steel are materials that are considered more economical than brass for this application. The major difficulties in the development of aluminum cartridge cases are those of the so-called "burn-through" problems[2,3,4]. Existing literature indicates that the sidewall of an aluminum cartridge case that had split during firing caused serious erosion of the case head and the chamber of a gun. Serious erosion damage in the M16 Rifle Chamber due to aluminum case splits has been observed[2,3]. With the initiation of the aluminum case program at Frankford Arsenal in July 1969, various tests were conducted to ascertain the seriousness, frequency, and the nature of the aluminum case failures. The test of the 5.56 mm cases made of 7039, 7075, and 7178 alloys showed an exceptionally high failure rate. Hence, from the economical point of view, the development of steel-cased cartridges is of great importance at the present time. In a recent development of steel cartridge cases, high-extraction forces were encountered that were caused by the sticking of the case to the chamber. This sticking condition arose because a steel cartridge case has less recovery than a brass case. This reduced recovery can be attributed to the fact that the modulus of elasticity of steel is much higher than the modulus of elasticity of brass.

The objective of this investigation is to develop a more rational nonlinear elastoplastic method for analyzing and designing a steel-cased cartridge and a chamber to remedy the sticking problem. The interaction of a steel-cased cartridge and the chamber of a gun will be studied parametrically. A set of design parameters such as cartridge case and chamber material properties, chamber pressure, cartridge configuration, the initial clearance between a case and a chamber, and the configuration of the chamber of a gun will be established to ensure uniform and improved performance of a steel-cased cartridge. In contrast to the usual assumption that the chamber is rigid, the chamber is considered to be deformed elastically in this investigation.

#### DEVELOPMENT OF AN INCREMENTAL THEORY

When a gun is fired, the propellant charge is ignited and the resulting propellant gas pressure causes the cartridge case to expand to the diameter of chamber, after which the case and the chamber expand together. The condition of free extraction of a case can be achieved if the recovery of the case from maximum firing strain exceeds that of the chamber.

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In the development of an incremental inelastic theory for a cartridge, a cylindrical coordinate system  $(r, \theta, z)$  is used with the  $z$  axis coincident with the axis of the cartridge. The longitudinal cross-section of a typical cartridge case is shown in Figure 1. The cartridge case is divided into a number of rings with  $z_0 = 0, z_1, z_2, \dots, z_n = L$ . Each ring is considered to be a thin-walled conical shell undergoing axisymmetric deformation.

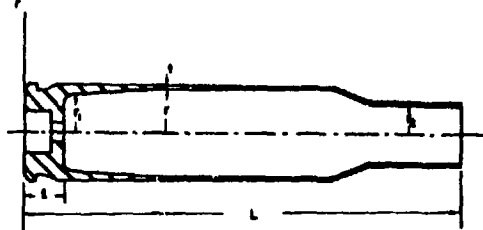


Fig. 1 Longitudinal Cross-Section of a Cartridge Case

For each increment of pressure,  $dP$ , the incremental stress components acting on a ring with radius  $r$  are

$$d\sigma_\theta = \frac{rdP}{t\cos\beta} \quad (1)$$

$$d\sigma_r = -\frac{t}{2r} d\sigma_\theta = -\frac{dP}{2\cos\beta} \quad (2)$$

$$d\sigma_z = \frac{dP}{2t\cos\beta} \quad \text{if } F \leq F_0 \quad (3)$$

$$= \frac{dP(r_1^2 - r_2^2)}{2rt\cos\beta} \quad \text{if } F > F_0 \quad (4)$$

where  $F_0$  is the bullet-pulling force

$$F = \pi r_2^2 P_g \quad (5)$$

The  $P_g$  is the propellant gas pressure. Note that  $dP = dP_g - dP_I$  where  $dP_I$  is the incremental interface pressure between the case and the chamber.

## Cartridge Case Loaded Into Inelastic Region

For any point of a cartridge that is loaded to an inelastic region, the Prandtl-Reuss incremental constitutive equations are assumed to be valid, i.e.,

$$\frac{d\epsilon_r^P}{s_r} = \frac{d\epsilon_\theta^P}{s_\theta} = \frac{d\epsilon_z^P}{s_z} \quad (6)$$

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where  $d\epsilon_r^P$ ,  $d\epsilon_\theta^P$ , and  $d\epsilon_z^P$  are incremental plastic strain components, and  $S_r$ ,  $S_\theta$ , and  $S_z$  are the components of deviator stress which are defined by

$$S_r = \sigma_r - S = \frac{1}{3} (2\sigma_r - \sigma_\theta - \sigma_z); \text{ etc.} \quad (7)$$

Since the total strain in an overstrained material is composed of an elastic and of a plastic component, i.e.,

$$\epsilon = \epsilon^e + \epsilon^P \quad (8)$$

The elastic-strain components  $\epsilon_r^e$ ,  $\epsilon_\theta^e$ , and  $\epsilon_z^e$  can be eliminated by Hooke's laws, then two independent equations can be derived [5,6] as:

$$\begin{aligned} & -\frac{1}{E_c} [(2\sigma_z - \sigma_r - \sigma_\theta) + \mu_c (2\sigma_r - \sigma_\theta - \sigma_z)] d\sigma_r + \frac{\mu_c}{E_c} [(2\sigma_z - \sigma_r - \sigma_\theta) - (2\sigma_r - \sigma_\theta - \sigma_z)] d\sigma_\theta \\ & + \frac{1}{E_c} [(2\sigma_r - \sigma_\theta - \sigma_z) + \mu_c (2\sigma_z - \sigma_r - \sigma_\theta)] d\sigma_z + (2\sigma_z - \sigma_r - \sigma_\theta) d\epsilon_r \\ & - (2\sigma_r - \sigma_\theta - \sigma_z) d\epsilon_z = 0 \end{aligned} \quad (9)$$

and

$$\begin{aligned} & \frac{\mu_c}{E_c} [(2\sigma_z - \sigma_r - \sigma_\theta) - (2\sigma_\theta - \sigma_z - \sigma_r)] d\sigma_r - \frac{1}{E_c} [(2\sigma_z - \sigma_r - \sigma_\theta) + \mu_c (2\sigma_\theta - \sigma_z - \sigma_r)] d\sigma_\theta \\ & + \frac{1}{E_c} [\mu_c (2\sigma_z - \sigma_r - \sigma_\theta) + (2\sigma_\theta - \sigma_z - \sigma_r)] d\sigma_z + (2\sigma_z - \sigma_r - \sigma_\theta) d\epsilon_\theta \\ & - (2\sigma_\theta - \sigma_z - \sigma_r) d\epsilon_z = 0 \end{aligned} \quad (10)$$

where  $E_c$  and  $\mu_c$  are modulus of elasticity and Poisson's ratio of case material, respectively.

In the development of an elastoplastic solution, the surface used to define the elastic limit is referred to as the yield surface. For linear strain-hardening nonisothermal material, the subsequent yield surface or loading function can be represented [7] as

$$\bar{\sigma} = (1-\alpha)\sigma_{yc} + \alpha E_c \bar{\epsilon} \quad (11)$$

where  $\alpha E_c$  is the slope of the straight line in the plastic region and  $\alpha$  may be considered as a strain-hardening factor for the case material,  $\sigma_{yc}$  is the yield stress of the case material in tension.  $\bar{\sigma}$  and  $\bar{\epsilon}$  are

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effective stress and effective strain, respectively[8]. Since  $\bar{\epsilon} = \bar{\epsilon}^e + \bar{\epsilon}^p$ , equation (11) can be reduced to the relation [9].

$$\begin{aligned} & \left\{ \frac{1}{2\bar{\sigma}} (2\sigma_r - \sigma_\theta - \sigma_z) + \frac{1+\mu_c}{E_c} \phi [(2\epsilon_r - \epsilon_\theta - \epsilon_z) - \frac{1+\mu_c}{E_c} (2\sigma_r - \sigma_\theta - \sigma_z)] \right\} d\sigma_r \\ & + \left\{ \frac{1}{2\bar{\sigma}} (2\sigma_\theta - \sigma_z - \sigma_r) + \frac{1+\mu_c}{E_c} \phi [(2\epsilon_\theta - \epsilon_z - \epsilon_r) - \frac{1+\mu_c}{E_c} (2\sigma_\theta - \sigma_z - \sigma_r)] \right\} d\sigma_\theta \\ & + \left\{ \frac{1}{2\bar{\sigma}} (2\sigma_z - \sigma_r - \sigma_\theta) + \frac{1+\mu_c}{E_c} \phi [(2\epsilon_z - \epsilon_r - \epsilon_\theta) - \frac{1+\mu_c}{E_c} (2\sigma_z - \sigma_r - \sigma_\theta)] \right\} d\sigma_z \\ & - \phi [(2\epsilon_r - \epsilon_\theta - \epsilon_z) - \frac{1+\mu_c}{E_c} (2\sigma_r - \sigma_\theta - \sigma_z)] d\epsilon_r \\ & - \phi [(2\epsilon_\theta - \epsilon_z - \epsilon_r) - \frac{1+\mu_c}{E_c} (2\sigma_\theta - \sigma_z - \sigma_r)] d\epsilon_\theta \\ & - \phi [(2\epsilon_z - \epsilon_r - \epsilon_\theta) - \frac{1+\mu_c}{E_c} (2\sigma_z - \sigma_r - \sigma_\theta)] d\epsilon_z = 0 \end{aligned} \quad (12)$$

in which

$$\bar{\sigma} = \frac{1}{\sqrt{2}} [(\sigma_r - \sigma_\theta)^2 + (\sigma_\theta - \sigma_z)^2 + (\sigma_z - \sigma_r)^2]^{1/2} \quad (13)$$

$$\bar{\epsilon}^p = \frac{\sqrt{2}}{3} [(\epsilon_r^p - \epsilon_\theta^p)^2 + (\epsilon_\theta^p - \epsilon_z^p)^2 + (\epsilon_z^p - \epsilon_r^p)^2]^{1/2} \quad (14)$$

and

$$\phi = \frac{2}{9} \frac{\alpha E_c}{1-\alpha} \frac{1}{\bar{\epsilon}^p} \quad (15)$$

Cartridge Case Loaded in Elastic Region

If the cartridge case is loaded in the elastic region, i.e.,  $\bar{\sigma} < \sigma_{yc}$ , the following stress-strain relations[10] have to be used.

$$\epsilon_r = \frac{1}{E_c} [\sigma_r - \mu_c (\sigma_\theta + \sigma_z)] \quad (16)$$

$$\epsilon_\theta = \frac{1}{E_c} [\sigma_\theta - \mu_c (\sigma_r + \sigma_z)] \quad (17)$$

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$$\epsilon_z = \frac{1}{E_c} [\sigma_z - \mu_c (\sigma_r + \sigma_\theta)] \quad (18)$$

At each station, six unknown incremental quantities exist  $d\sigma_r$ ,  $d\sigma_\theta$ ,  $d\sigma_z$ ,  $d\epsilon_r$ ,  $d\epsilon_\theta$ , and  $d\epsilon_z$  that must be determined for each incremental step of pressure  $dP$ . Whether the cartridge case is loaded in the plastic region or in the elastic region, the six equations listed above can be used to solve for these six unknown incremental quantities of stresses and strains. With these calculated strain components and the following strain-displacement relations

$$\epsilon_\theta = \frac{u_c}{r} \quad (19)$$

and

$$\frac{dw}{dz} = \epsilon_z \quad (20)$$

where  $u$  and  $w$  are, respectively, the displacement components in the radial and axial directions, the displacement of the cartridge at radius  $r$  can be calculated. By use of eq. (19)  $u_c$  can be evaluated

$$u_c = r\epsilon_\theta \quad (21)$$

Let  $u_0$  be the initial clearance between the cartridge case and the chamber, then the displacement of the chamber at the inner surface,  $u_b$ , can be written

$$u_b = u_c - u_0 \quad (22)$$

If the chamber is assumed to be a thick-walled cylinder subjected to internal pressure  $P_I$ , then [10]

$$u_b = u_c - u_0 = \frac{P_I a}{E_b} \left[ \frac{b^2 + a^2}{b^2 - a^2} + \mu_b \right] \quad (23)$$

Where  $E_b$  and  $\mu_b$  are modulus of elasticity and Poisson's ratio for the chamber material,  $a$  and  $b$  are the inner and outer radii of the chamber. The interface pressure  $P_I$  of chamber and case is then given by

$$P_I = \frac{(u_c - u_0) E_b}{a \left[ \frac{b^2 + a^2}{b^2 - a^2} + \mu_b \right]} \quad \text{if } u_c > u_0 \quad (24)$$

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and

$$P_I = 0 \quad \text{if } u_c \leq u_0 \quad (25)$$

Note that

$$P_g = P + P_I \quad \text{if } u_c > u_0 \quad (26)$$

and

$$P_g = P \quad \text{if } u_c \leq u_0 \quad (27)$$

### COMPUTATIONAL PROCEDURE

#### Loading

Since a large displacement of the cartridge case may be involved in the present case-chamber interface problem, the true displacement of the cartridge case at the peak pressure,  $P_{\max}$ , would not be known at the beginning of the loading process. Hence, an incremental loading procedure will be utilized to obtain solutions to the problem indicated in this investigation. To obtain a numerical elastoplastic solution of case-chamber interface problem, one must first determine the pressure-time relationship. A typical pressure-time curve of a 6 mm ammunition is given in Figure 2. The loading path is divided into a number of increments.

At the beginning of each increment of loading, the distribution of stresses and strains is assumed to have been calculated in the previous time-interval. For each increment of pressure, the calculation procedure can be stated as follows:

Step 1. Specify an increment of pressure  $\Delta P_1$  acting on the case, then

$$P_1 = P_{1-1} + \Delta P_1$$

Step 2. Calculate  $d\sigma_\theta$ ,  $d\sigma_r$ , and  $d\sigma_z$  by using eqs. (1), (2), (3) or (4).

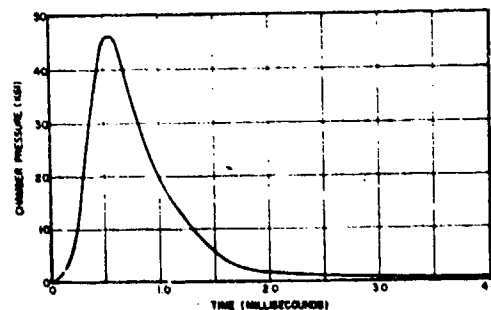


Fig. 2 A Typical Pressure-Time Curve for a 6mm Cartridge Case

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Step 3. Calculate

$$\sigma_{\theta} = \sigma_{\theta} \Big|_{\text{before an increasing of the load}} + d\sigma_{\theta}$$

$\sigma_r$  and  $\sigma_z$  are calculated in the same manner.

Step 4. Calculate the effective stress by using

$$\bar{\sigma} = \frac{1}{\sqrt{2}} [(\sigma_r - \sigma_{\theta})^2 + (\sigma_{\theta} - \sigma_z)^2 + (\sigma_z - \sigma_r)^2]^{1/2}$$

Step 5. Calculate  $d\epsilon_r$ ,  $d\epsilon_{\theta}$ , and  $d\epsilon_z$  by using eqs. (9), (10), and (12) if  $\bar{\sigma} > \sigma_{yc}$ , or by using eqs. (16), (17), and (18) if  $\bar{\sigma} \leq \sigma_{yc}$ .

Step 6. Calculate

$$\epsilon_{\theta} = \epsilon_{\theta} \Big|_{\text{before an increasing of the load}} + d\epsilon_{\theta}$$

$\epsilon_r$  and  $\epsilon_z$  are calculated in the same manner.

Step 7. Compute the radial displacement of the case

$$u_c = r\epsilon_{\theta}$$

Step 8. Compute the bore displacement of the chamber

$$\begin{aligned} u_b &= u_c - u_0 & \text{if } u_c > u_0 \\ &= 0 & \text{if } u_c \leq u_0 \end{aligned}$$

where  $u_0$  is the initial clearance between the case and the chamber.

Step 9. Compute the interface pressure

$$P_I = \frac{(u_c - u_0) E_b}{a \left[ \frac{b^2 + a^2}{b^2 - a^2} + \mu_b \right]}$$

Step 10. Compute propellant gas pressure

$$P_g = P_i + P_I$$

if  $P_g < P_{\max}$ , let  $r = r_0 + u_c$ , then refer back to Step 1. All computations to continue.

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Step 11. If  $P_g = P_{\max}$ , then let

$$\bar{P}_I = P_I, \bar{u}_c = u_c, \bar{u}_b = u_b, \text{ and } r_{\max} = u_o + \bar{u}_c$$

Note that  $\bar{P}_I$ ,  $\bar{u}_c$ ,  $\bar{u}_b$ , and  $r_{\max}$  are the interface pressure between the case and the chamber, the displacement of the case, the displacement of the chamber at the bore, and the radius of the case at the peak pressure, respectively.

### Unloading

During the unloading process, the behavior of the cartridge case and the chamber is considered to be elastic. The dimensions used are the dimensions of the case and the chamber computed at the peak pressure. A negative pressure is applied to the case during the unloading process. The result of unloading is then superposed on the result at the peak pressure and, hence, the interference pressure and the extraction force can be determined.

Step 1. Specify  $-\Delta P_I$ , then calculate  $P_I$  by

$$P_I = P_{I-1} - \Delta p_I$$

Step 2. Compute  $d\sigma_r$ ,  $d\sigma_\theta$ , and  $d\sigma_z$ .

Step 3. Compute  $\sigma_r$ ,  $\sigma_\theta$  and  $\sigma_z$ .

Step 4. Compute  $d\epsilon_r$ ,  $d\epsilon_\theta$ , and  $d\epsilon_z$  by using eqs. (16), (17), and (18).

Step 5. Compute  $\epsilon_\theta$ ,  $\epsilon_r$  and  $\epsilon_z$ .

Step 6. Compute the radial displacement of the case

$$u_c = \frac{r}{E_c} [\sigma_\theta - \mu_c(\sigma_r + \sigma_z)]$$

Step 7. Compute interface pressure

$$P_I = \frac{u_c E_b}{a \left[ \frac{b^2 + a^2}{b^2 - a^2} + \mu_b \right]}$$

Step 8. Applying the superposition principle, the interface pressure between the case and the chamber, the case and the chamber displacements at unloading can be computed by the following:

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$$\bar{P} = P_I + \bar{P}_I \quad \text{if } |u_c| < \bar{u}_b$$

$$= 0 \quad \text{if } |u_c| \geq \bar{u}_b$$

$$\bar{u} = u_c + \bar{u}_c$$

$$\bar{u}_b = u_b + \bar{u}_b \quad \text{if } |u_c| \leq \bar{u}_b$$

$$= 0 \quad \text{if } |u_c| > \bar{u}_b$$

where  $\bar{p}$  is the interface pressure during unloading

$u_c$  is the case displacement during unloading

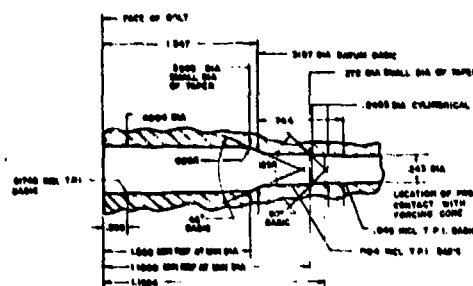
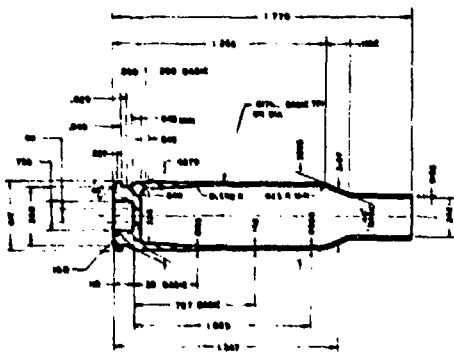
and  $u_b$  is the bore displacement of the chamber during unloading.

Step 9. Compute  $P_g = P_I + P_{II}$  if  $P_g + P_{\max} > 0$ , then let  $r = r_{\max} + u_c$ , refer back to Step 1. All computations to continue.

Step 10. If  $P_g + \bar{P}_g \approx 0$ , then compute the extraction force. Note that when the unloading process is completed, the interface pressure is automatically computed at Step 8 which is used to compute the extraction force with assigned friction coefficient between the case and the chamber.

## ANALYSIS OF RESULTS

A 6mm steel cartridge case and the configuration of the inner surface of a chamber considered in this investigation are shown in Figures 3 and 4, respectively. The outer diameter of the chamber is



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assumed to be one inch. To obtain numerical solutions, the cartridge case is divided into thirty-two rings. The peak pressure, the thickness, the initial clearance between case and chamber, and the material properties such as yield strength, strain-hardening, and modulus of elasticity, etc., for each ring are considered to be independent design parameters. Since a steel cartridge case is considered in this investigation, the modulus of elasticity will be considered as a constant,  $E_c = 30 \times 10^6$  psi, for each ring.

## Effect of Yield Strength of Case Material

The yield strength of a steel-cased cartridge is a very important factor with respect to the sticking problem of the steel cartridge case. The effect of yield strength of a case material on the extraction force is shown in Figure 5. The extraction force can be reduced if a case is made of a higher strength material, as indicated in Figure 5. However, increasing the strength of the material is limited by other material properties such as hardness and elongation. If the hardness of a cartridge case is increased, the ductility of the material will be reduced and, hence, the incidence of a split case will be increased.

The effect of the yield strength on the functioning of a steel-cased cartridge is illustrated in Figure 6. In Figure 6, the slope of line OA represents the modulus of elasticity, E, of the case. The Curve  $O\sigma_{yc1}D$  represents the stress-strain curve of a normal steel-cased cartridge, where  $\sigma_{yc1}$  is the yield strength. OB represents the initial clearance between the case and the chamber. BC represents the elastic expansion of the chamber under firing condition. Beyond the yield point  $\sigma_{yc1}$ , plastic extension takes place up to a point D. While the pressure

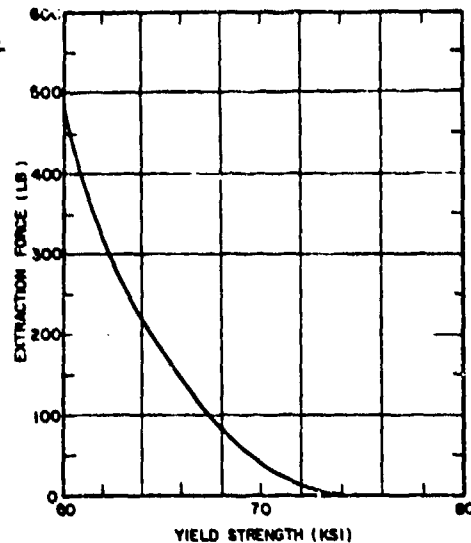


Fig. 5 Effect of the Yield Strength of the Case Material on the Extraction Force

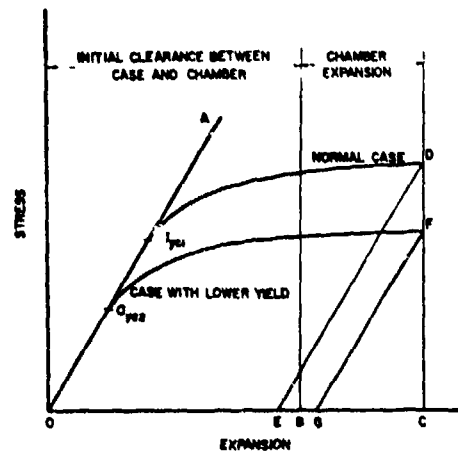


Fig. 6 Effect of the Yield Strength on the Functioning of a Cartridge Case

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is starting to release, elastic recovery takes place along the line DE which is parallel to line OA. OE represents the permanent expansion of the case. If the expansion of the chamber is assumed to be completely elastic, then the chamber will return to B after firing. The distance EB thus represents the clearance between the case and the chamber after firing. Hence,  $EB \geq 0$  is the condition of free extraction of a cartridge case. If a steel cartridge case has a lower yield strength,  $\sigma_{yc2}$ , as shown in Figure 5, the stress-strain curve is then given by curve  $OG_{yc2}F$ . The recovery of this case will follow the line FG which is parallel to OA. The recovery of the case CG is less than the recovery of the chamber BC; hence, an interference occurs between the case and the chamber. The difficulty of extraction of a steel cartridge case with lower yield strength is indicated in this figure.

## Effect of the Peak Pressure

The magnitude of the peak pressure is also a very important factor in the sticking problem of a steel cartridge case. The effect of the peak pressure on the resulting extraction force is shown in Figure 7. In this figure, note that the incidence of cases that stick to the chamber can be significantly reduced or eliminated if the peak pressure can be reduced to a certain level. A reduction of peak pressure (all other factors held constant) will reduce the round impulse and velocity. One method of maintaining the round impulse and the velocity while the peak pressure is being reduced is to cause the Pressure-Time (P-T) curve to become flatter.

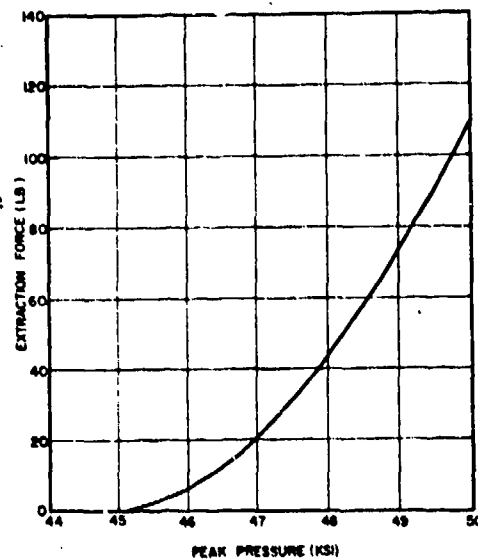


Fig. 7 Effect of the Peak Pressure on the Extraction Force

The effect of the peak pressure on the functioning of a steel-cased cartridge is illustrated in Figure 8. The pressure-expansion relation of a steel-cased cartridge, as shown in this figure, is given by the curve OABC. OD represents the initial clearance between the case and the chamber. The recovery of a steel-cased cartridge at the normal peak pressure is given by EG which is greater than the chamber recovery DG. Hence, free extraction of a case can be achieved. However, if the peak pressure of the propellant gas is greater than the normal peak pressure, then more plastic expansion of the case will take place, as shown by point C in Figure 8. The recovery of the

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cartridge in this case is given by FH which is less than the chamber DH. Hence, an interference between the cartridge and the chamber will take place.

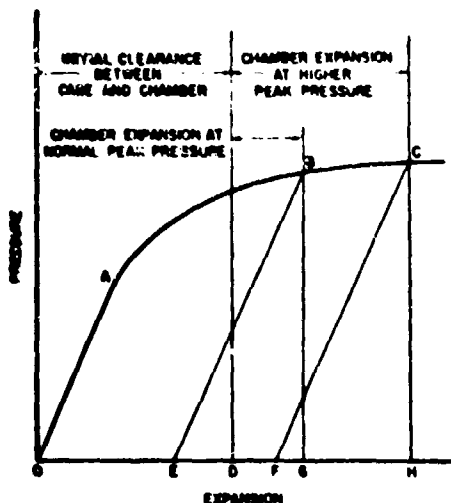


Fig. 8 Effect of the Peak Pressure on the Functioning of a Cartridge Case

#### Effect of the Strain-Hardening of Case Material

The effect of the strain-hardening of the case material on the extraction force is shown in Figure 9. The extraction force can be reduced if a case is made of a steel with higher strain-hardening property as indicated in Figure 9. However, if the same chamber expansion is considered, the stress in the cartridge with higher strain-hardening is higher than the stress in the cartridge with lower strain-hardening. Hence, the cartridge case with higher strain-hardening may be a contributing factor to failure by splitting.

The effect of the strain-hardening on the functioning of a steel cartridge case can be illustrated by use of Figure 10. The stress-strain curves of a normal steel-cased cartridge and a steel-cased cartridge with lower strain-hardening are given by OA and OB, respectively. After each firing, the normal cartridge case is unloaded

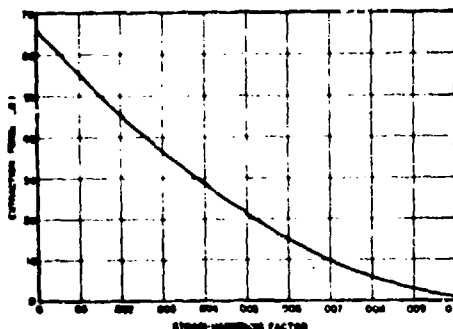


Fig. 9 Effect of the Strain-Hardening Property of the Case Material on the Extraction Force

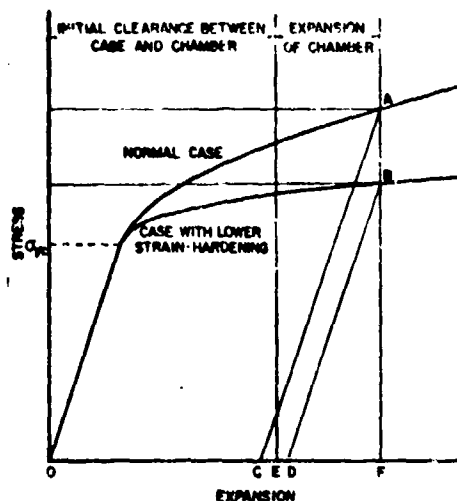


Fig. 10 Effect of the Strain-Hardening on the Functioning of a Cartridge Case

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from A to C. The permanent expansion of this normal cartridge case is given by OC which is less than the initial clearance between the cartridge and the chamber. Hence, free extraction is indicated. However, after each firing, a cartridge case with lower strain-hardening is unloaded from B to D. The permanent expansion of this cartridge case is given by OD which is greater than the initial clearance between the cartridge and the chamber. Hence, the interference between the cartridge and the chamber is indicated.

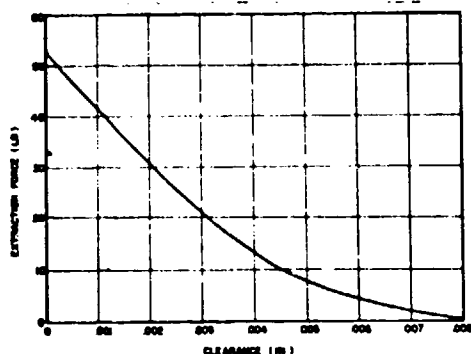


Fig. 11 Effect of the Clearance Between the Case and the Chamber on the Extraction Force

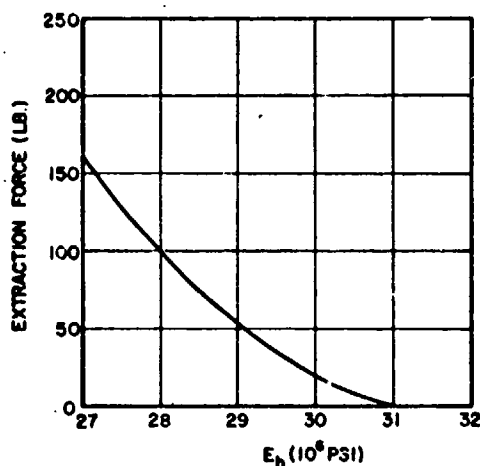


Fig. 12 Effect of the Modulus of Elasticity of a Chamber Material on the Extraction Force

#### Effect of Initial Clearance Between Cartridge Case and Chamber

The relation of clearance between the cartridge case and the chamber, and the extraction force is shown graphically in Figure 11. Note that the increasing of an initial clearance will reduce the force required to extract a case that is sticking to the chamber. However, this increasing of the initial clearance may increase the incidence of malfunctions.

#### Effect of the Modulus of the Elasticity of a Chamber Material

The effect of the modulus of the elasticity of a chamber material on the extraction force is shown in Figure 12. The extraction force can be reduced if the modulus of elasticity of the chamber material is increased as indicated in this figure. This can be illustrated as follows: When the modulus of the elasticity of the chamber is increased, the elastic expansion of the chamber will be decreased and, hence, the permanent expansion of the case is reduced. Therefore, the extraction force of the cartridge is reduced.

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#### CONCLUSIONS

A nonlinear incremental elastoplastic solution technique has been developed to solve problems arising from the interaction of a steel-cased cartridge and a chamber. Both nonlinear material response and geometric nonlinearity have been considered in this investigation. Nonlinearity of material properties has been taken into account by use of theories of plasticity and Prandtl's constitutive equations. An incremental loading procedure has been used to consider the large deformation of the cartridge case.

The interaction of the steel-cased cartridge and the chamber of the gun has been parametrically studied. Guidance for the selection of design variables such as yield strength and strain-hardening properties of a cartridge case material, peak chamber pressure, cartridge configuration, the initial clearance between a case and a chamber, the configuration, and the material property of the chamber of a gun is graphically presented in this paper. The effects of yield strength and strain-hardening properties of material and peak chamber pressure on the functioning of a steel-cased cartridge in a chamber are illustrated.

#### REFERENCES

1. Engineering Design Handbook, AMCP 706-297, "Ammunition Series," Army Materiel Command, July 1964.
2. Skochko, L., Rosenbaum, M., and Donnard, R.E., "Aluminum Cartridge Case, Concepts Task-Work Summary," Report R-3001, Frankford Arsenal, March 1974.
3. Donnard, R.E., and Hennessy, T.J., "Aluminum Cartridge Case Feasibility Study Using the M16A1 Rifle with the 5.56 MM Ball Ammunition as the Test Vehicle," Frankford Arsenal Report R-2065, Nov 1972.
4. Rosenbaum, M., Hennessy, T.J., Marziano, S.J., and Donnard, R.E., "Design and Development of a 7.62 MM Aluminum Alloy Cartridge Case," Frankford Arsenal Report R-2062, Jan 1973.
5. Chu, S.C., "A More Rational Approach to the Stress Analysis of Gun Tube," Proceeding of the 1974 Army Science Conference, Vol. I.
6. Chu, S.C., and Vasilakis, J.O., "Inelastic Behavior of Thick-Walled Cylinders Subjected to Nonproportionate Loading," Experimental Mechanics, March 1973.
7. Hill, R., The Mathematical Theory of Plasticity, Oxford, Clarendon Press, 1950.
8. Smith, J.O., and Sidebottom, O.M., Inelastic Behavior of Load-Carrying Members, John Wiley & Sons, Inc., 1965.
9. Chu, S.C., "A More Rational Approach to the Problem of Elastoplastic Thick-Walled Cylinder," J. of Franklin Inst., Vol. 294, 1972.
10. Timoshenko, S., and Goodier, J.N., Theory of Elasticity, McGraw-Hill, New York, 1951.

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